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Changes in prevalence of, and risk factors for, lameness in random samples of English sheep flocks: 2004 - 2013

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1 **Abstract**

2 The aims of this study were to update the prevalence of lameness in sheep in England
3 and identify novel risk factors. A total of 1260 sheep farmers responded to a postal
4 survey. The survey captured detailed information on the period prevalence of
5 lameness from May 2012 - April 2013 and the prevalence and farmer naming of
6 lesions attributable to interdigital dermatitis (ID), severe footrot (SFR), contagious
7 ovine digital dermatitis (CODD) and shelly hoof (SH), management and treatment
8 of lameness, and farm and flock details.

9 The global mean prevalence of lameness fell between 2004 and 2013 from 10.6% to
10 4.9% and the geometric flock mean period prevalence of lameness fell from 5.4%
11 (95% CL: 4.7-6.0%) to 3.5% (95% CI: 3.3%-3.7%). In 2013, more farmers were
12 using vaccination and antibiotic treatment for ID and SFR and fewer farmers were
13 using foot trimming as a routine or in therapeutic treatment than in 2004.

14 Two over-dispersed Poisson regression models were developed with the outcome the
15 period prevalence of lameness, one investigated associations with farmer estimates of
16 prevalence of the four foot lesions and one investigated associations with
17 management practices to control and treat lameness and footrot. A prevalence of ID
18 >10%, SFR >2.5% and CODD >2.5% were associated with a higher prevalence of
19 lameness compared with those lesions being absent, however, the prevalence of SH
20 was not associated with a change in risk of lameness.

21 A key novel management risk associated with higher prevalence of lameness was the
22 rate of feet bleeding / 100 ewes trimmed / year. In addition, vaccination of ewes once
23 per year and selecting breeding replacements from never-lame ewes were associated
24 with a decreased risk of lameness. Other factors identified as associated with a lower

25 risk of lameness, for the first time in a random sample of farmers and a full risk
26 model, were recognising lameness in sheep at locomotion score 1 compared with
27 higher scores, treatment of the first lame sheep in a group compared with >5,
28 treatment of lame sheep within 3 days, ease of catching lame sheep and quarantine
29 for >21 days. A previously known factor associated with a lower risk of lameness
30 was footbathing to prevent ID. We conclude that the prevalence of lameness in sheep
31 in England has fallen and that this might be in part because of increased uptake of
32 managements previously reported as beneficial to control lameness. Routine foot
33 trimming should be avoided.

34 **Introduction**

35 Lameness costs the sheep industry in GB £24 - £80 million per annum (Nieuwhof
36 and Bishop, 2005; Wassink, *et al.*, 2010). Financial losses occur because of reduced
37 rates of lambs born and reared and slower growth rates of lame lambs (Wassink, *et*
38 *al.*, 2010).

39 In 2004 a random sample of 3000 English sheep farmers were sent a one year
40 retrospective questionnaire requesting information on types of foot lameness (Kaler
41 and Green 2008) and management of lameness in their flock (Kaler and Green 2009).
42 A total of 809 (27%) farmers replied after two reminders. The geometric mean
43 prevalence of lameness was 5.4% (95% CI 4.7 - 6.0) and the global mean prevalence
44 of all lameness was 10.6% with an estimated 6.9%, 3.7%, 2.4%, 1.9%, 0.9% and
45 0.8% of the sheep lame with at least one of interdigital dermatitis (ID), severe footrot
46 (SFR), contagious ovine digital dermatitis (CODD), shelly hoof (SH), foot abscess
47 and toe granuloma respectively. ID and SFR dominated the within and between flock
48 prevalence of lameness with 80% lame sheep with these two lesions and 90%
49 farmers reporting that it was the most common cause of lameness in their flock.

50 In the same study, factors associated with a higher annual period prevalence of all
51 lameness (Kaler and Green 2009) were routine foot trimming once or more per year
52 compared with no routine foot trimming, routine footbathing and a stocking density
53 of >8 ewes/ha. Separating lame sheep from sound at pasture was associated with a
54 lower risk of lameness. In other observational studies with non-random samples of
55 farmers, lower farmer reported prevalence of lameness was associated with
56 quarantine of new and returning stock, isolation and treatment of all sheep lame with
57 ID or SFR with parenteral and topical antibacterial treatments (Wassink *et al.*, 2003),

58 footbathing and turning a flock to clean pasture to treat ID (Wassink et al., 2004) and
59 catching the first mildly lame sheep in a group for treatment within 3 days of first
60 becoming lame (Kaler and Green 2008). Factors associated with a higher prevalence
61 of lameness were routine foot trimming (Grogono-Thomas and Johnston, 1997;
62 Kaler and Green, 2009; Wassink, *et al.*, 2003; 2004; 2005), footbathing to treat
63 footrot (Wassink et al., 2003, 2004) and a stocking density >8 ewes/ha (Wassink et
64 al., 2003). Two clinical trials have demonstrated that recovery from footrot is most
65 rapid when sheep are treated with parenteral and topical antibacterials with no paring
66 of the diseased foot (Kaler et al., 2010; 2012).

67 In 2011 the Farm Animal Welfare Council proposed that the prevalence of lameness
68 in 2004 of 10% should fall to 5% by 2016 and 2% by 2021 (FAWC, 2011) with
69 farmer uptake of existing knowledge. Since 2006 there have been a series of
70 campaigns in England run by AHDB Beef & Lamb (the levy body for beef and sheep
71 farmers) comprising paper and electronic literature and farmer meetings. The aims of
72 the current study were, given the above technology transfer, to test the hypothesis
73 that the prevalence of lameness in sheep had fallen since 2004 and farmers had
74 changed managements of lameness and to identify novel factors associated with low
75 prevalence of lameness in 2013.

76 **Materials and Methods**

77 **Questionnaire design and administration**

78 A postal questionnaire (available on request) was developed by a group of
79 researchers at the Universities of Warwick and Nottingham. Part of the questionnaire
80 captured detailed information on the period prevalence of lameness, recognition of
81 four foot lesions, management and treatment of lameness, ID and SFR and details

82 about farm and flock. It was based on previous questionnaires designed for research
83 into sheep lameness, available literature and expertise from within the group.
84 Questions were based on the period May 2012 to April 2013. Most questions were
85 closed or semi-closed with an 'other' option.

86 In June 2013, the questionnaire was sent to 4000 lowland sheep farmers in England
87 with >199 ewes; lists were obtained from DEFRA and AHDB Beef & Lamb who
88 selected flocks randomly stratified by county and size with duplicated farmers
89 removed. Up to two reminder letters, the second with a second copy of the
90 questionnaire, were sent to non-respondents; respondents were sent a thank you
91 acknowledgement.

92 **Data preparation and preliminary analysis**

93 Double data entry was done by an outside agency (Wyman Dillon Ltd, Bristol) and
94 data were stored in Microsoft Excel. Data cleaning was done using specifically
95 written code in Python using Pandas, SciPy and NumPy toolkits (McKinney, 2010;
96 Oliphant, 2007; Pérez and Granger 2007). Data were stored in Microsoft Access.

97 For each question, frequency distributions and measures of central tendency and
98 dispersion were calculated. Farms were excluded from analysis if data on either the
99 flock size or the annual period prevalence of lameness were missing. The geometric
100 mean and s.e. were calculated for the annual period prevalence of lameness. The
101 global arithmetic mean prevalence of lameness was calculated for the year from the
102 total number of lame sheep divided by the total number of sheep in the study.

103 Characteristic images and descriptions of four foot lesions (ID, SFR, CODD and SH)
104 were included in the questionnaire (e.g. Figure 1) and farmers were asked what they
105 named each lesion, whether they had seen the lesion in their flock in the period and,

106 if so, what percentage of their ewes had the lesion. It was possible to identify
107 whether farmers were recognising but misnaming a lesion by comparing the
108 distribution of responses of correctly an incorrectly named responses using the
109 techniques described in full elsewhere (Kaler and Green 2008a). The global
110 arithmetic mean prevalence of each lesion and the prevalence of each lesion as a
111 percentage of all lesions were calculated.

112 From the management questions on routine foot trimming a single variable the rate
113 of feet bleeding / 100 ewes trimmed / year was calculated from the frequency of
114 routine trimming, the percentage of sheep trimmed at each trimming event and the
115 percentage of sheep that bled during each routine trim.

116 **Multivariable modelling of associations between prevalence of foot lesions and**
117 **lameness and management practices and lameness**

118 Two over-dispersed Poisson regression models (Dohoo, *et al.*, 2003) were used
119 (MLwiN 2.30, (Rasbash, *et al.*, 2014) to estimate univariable and multivariable
120 associations. The outcome variable was the period prevalence of lameness between
121 May 2012 and April 2013 and the first model investigated associations with the four
122 foot lesions and the second with management strategies.

123 The outcome was the number of lame sheep in the flock offset by the natural
124 logarithm of the expected number of lame sheep in the flock. The model had a log
125 link function and took the form

126
$$\text{Number of cases on } farm_j = \alpha + offset + \beta_j X_j + e_j$$

127 Where α is the intercept, \sim is a log link function, *offset* is the natural logarithm of
128 the number of expected lame sheep on each farm, β_j are the coefficients for a vector
129 of X_j explanatory variables which vary by farm j , and e_j is the residual random error.

130 The prevalence of four foot lesions ID, SFR, CODD and SH were categorised and
131 added into the model as explanatory variables to identify lesions associated with a
132 change in the overall prevalence of lameness reported by farmers.

133 To investigate the management factors associated with the period prevalence of
134 lameness, variables were grouped into 9 sub-categories and a model built for each
135 sub-category. The sub-categories were recognising and catching lame sheep,
136 treatment of sheep with footrot and interdigital dermatitis, routine flock trimming,
137 flock footbathing, culling and replacement of ewes, vaccination, whole flock
138 antibiotic treatment, biosecurity and characteristics of the farm and farmer.

139 In each sub-model univariable associations between all explanatory variables and the
140 outcome were screened. Variables were considered significant when the 95%
141 confidence intervals did not include unity (Wald's test for significance). A manual
142 forward selection process (Dohoo, *et al.*, 2003) was used to test variables in the
143 model and significant explanatory variables were retained in the model.

144 The variables that were significant in the 9 multivariable sub-models were tested in
145 an overall multivariable model which was also built using a manual forward
146 selection process. Significant variables (Wald's test for significance) were retained in
147 the model. All variables, regardless of their inclusion in the sub-models, were re-
148 tested in the final model and included in the model if significant (Cox and Wermuth,
149 1996). Model fit was assessed using Pearson's residuals against the predicted value.

150 **Associations between variables**

151 The Pearson chi-square test was used to investigate associations between categorical
152 variables. ANOVAs and non-parametric equivalents were used to investigate
153 associations between continuous and categorical variables.

154 **Results**

155 **Response rate and descriptive statistics**

156 A total of 1348 questionnaires were returned after two reminders. Questionnaires
157 missing data on flock size or lameness prevalence were excluded from the analysis.
158 There were 1260 (31.5%) usable responses. There were similar response proportions
159 across counties. Some respondents were from hill or upland farms and others have
160 <200 ewes. These factors were added to the models. Not all respondents answered all
161 questions. The median flock size was 350 ewes (IQR: 230-550). The global mean
162 prevalence of lameness in ewes was 4.9%, the data were skewed and the geometric
163 mean period prevalence of ewe lameness per flock was 3.5% (95% CI: 3.3%-3.7%)
164 and lamb lameness was 2.6% (95% CI: 2.3%-2.8%).

165 **Prevalence, proportional prevalence and farmer naming of lesions (Table 1)**

166 The most prevalent foot lesion by farm was ID, which was present on 90.5% of
167 farms. SFR was present on 81.6% of farms, CODD on 48.7% of farms and SH on
168 67.0% of farms (Table 1). The geometric mean prevalence of lesions within flocks
169 was 4.5% for ID and 3.1% for SFR, 2.3% for CODD and 2.9% for SH. The global
170 mean prevalence of foot lesions was higher than the estimated prevalence of
171 lameness at 10.2%, presumably because not all lesions were associated with
172 lameness (Table 2); ID and SFR together account for 68.0% of lesions. SFR and
173 CODD and SFR and ID were moderately correlated (0.46). Most farmers named ID

174 (88.5%) and SFR (81.2%) correctly but fewer named CODD (51.0%) and SH
175 (57.6%) correctly. As in 2004, incorrectly identified foot lesions were most
176 commonly misnamed SFR.

177 **Models of four foot lesions associated with lameness (Table 2)**

178 There was a higher RR of lameness in flocks with a prevalence of ID lesions >10%
179 (RR 1.52, 95% CI: 1.20-1.92) compared with farmers who reported no ID lesions in
180 their flocks, however, there was a significantly lower RR of lameness in flocks with
181 a >0-2.5% prevalence of ID (RR 0.72, 95% CI: 0.57-0.91) compared with a zero
182 prevalence of ID.

183 The RR of lameness was significantly higher in flocks as the prevalence of SFR
184 lesions increased from >2.5-5% - >10% compared with flocks without SFR lesions.
185 The RR of lameness was significantly higher in flocks with a prevalence of CODD
186 of >2.5-5% - >10% compared with flocks without CODD lesions. There was a
187 significantly lower RR of lameness in flocks with a low (<2.5%) prevalence of SH
188 (RR 0.85, 95% CI: 0.75-0.97) compared to a zero prevalence of shelly hoof. Higher
189 prevalences of SH were not associated with higher RR of lameness. There were
190 strong positive correlations between the prevalence lesions.

191 **Multivariable over dispersed Poisson model of management factors associated**
192 **with the period prevalence of lameness in sheep (Table 3)**

193 The variables and nine sub-models on management factors associated with the period
194 prevalence of lameness are presented in Supplementary Tables 1 and 2. There has
195 been an increase in the percentage of farmers who have stopped routine and
196 therapeutic foot trimming and started to use vaccination, select replacements from

197 non-lame ewes and always-use parenteral antibiotics to treat footrot (Supplementary
198 tables).

199 In the final model, the RR of lameness was higher in flocks when farmers recognised
200 sheep lame with a locomotion score (Kaler et al., 2009) of 2 (RR 1.19, 95% CI: 1.08-
201 1.30) compared with a score of 1. The RR of lameness in the flock was higher when
202 farmers waited until 6-10 sheep (RR 1.28, 95% CI: 1.08-1.52) or more than 10 sheep
203 in a group were lame (RR 1.37, 95% CI: 1.16-1.62) compared with farmers who
204 treated the first lame sheep in a group. The RR of lameness was higher in flocks
205 where farmers treated sheep within a week (RR 1.36, 95% CI: 1.10-1.66) or longer
206 than a week (RR 1.43, 95% CI: 1.14-1.80) compared with flocks where sheep were
207 treated the first day farmers saw them lame; approximately 50% farmers waited a
208 week or more before treating lame sheep. The RR of lameness was higher when
209 farmers reported that catching individual lame sheep was difficult / very difficult
210 (RR 1.13, 95% CI 1.00 - 1.28).

211 Farmers who reported none or <1 / 100 ewes / year feet bled during routine foot
212 trimming did not have a significantly different RR of lameness in their flocks
213 compared with farmers who did not routinely trim sheep feet. The RR was higher in
214 flocks where 1 - <5% of sheep bled (RR 1.33, 95% CI: 1.19-1.49), 5 - 10% (RR 1.39,
215 95% CI: 1.18-1.63) or >10% of sheep bled (RR 1.69, 95% CI: 1.43-1.99).

216 Footbathing all ewes for any reason was not associated with a significantly different
217 RR of lameness from never footbathing ewes. However, footbathing specifically to
218 treat footrot was associated with a higher risk of lameness (RR 1.12, 95% CI: 1.01-
219 1.24) compared with not footbathing for this reason, whilst footbathing to prevent ID
220 was associated with a lower risk of lameness in the flock (RR 0.87, 95% CI: 0.79-
221 0.96) compared with not footbathing to prevent ID. Footbathing at turnout, (RR 1.31,

222 95% CI: 1.07-1.59) and new sheep on arrival was associated with a higher risk of
223 lameness (RR 1.18, 95% CI: 1.05-1.33) compared with not footbathing at these
224 times.

225 Overall, culling sheep that had previously been lame was not associated with a
226 significant change in the RR of lameness in the flock, regardless of the number of
227 times that sheep had been lame before they were culled. However, flocks where
228 farmers relied on their memory to identify sheep for culling had a higher RR of
229 lameness (RR 1.22, 95% CI: 1.08-1.38) than flocks not managed in this way.
230 Farmers who avoided selecting replacement ewes from mothers who were repeatedly
231 lame had a lower RR of lameness (RR 0.77, 95% CI: 0.60-0.99) compared with
232 farmers who did not practice this management. Flocks vaccinated with Footvax
233 (MSD Animal Health) had a lower RR of lameness (RR 0.80, 95% CI: 0.71-0.90)
234 than flocks not vaccinated.

235 Farmers who “sometimes” checked the feet of new sheep on arrival had a lower RR
236 of lameness in their flocks (RR 0.81, 95% CI: 0.69-0.95) than flocks where farmers
237 who “never” checked. Flocks where new sheep were isolated on arrival for more
238 than three weeks had a lower RR of lameness (RR 0.82, 95% CI: 0.70-0.95)
239 compared with flocks where new sheep were not isolated. Where sheep left the farm
240 and then returned the RR of lameness was higher when sheep left for sheep shows,
241 (RR 1.30, 95% CI: 1.08-1.56) and summer grazing (RR 1.19, 95% CI: 1.07-1.33)
242 compared with flocks that did not leave for these reasons. Flocks where sheep left for
243 market and later returned had a lower RR of lameness (RR 0.72, 95% CI: 0.53-0.96)
244 compared with flocks that did not leave for this reason.

245 The RR of lameness was lower in hill flocks (0.70, 95% CI: 0.52-0.92) and lowland
246 flocks (RR 0.82, 95% CI: 0.73-0.93) than upland flocks. The RR of lameness was

247 lower on organic farms (RR 0.69, 95% CI: 0.54-0.88) than non-organic. Farmers
248 whose flocks produced breeding stock had a lower RR of lameness (RR 0.87, 95%
249 CI: 0.79-0.97) compared with flocks that did not produce breeding stock. The
250 prevalence of lameness in lambs was positively associated with the prevalence of
251 lameness in ewes; RR 1.03 (95% CI: 1.03-1.04) for each percent increase in lamb
252 lameness. Increasing flock size was associated with a lower RR of lameness (RR
253 0.74, 95% CI: 0.63-0.86) for each log10 increase in flock size.

254 The plot of Pearson residuals against the predicted values (Supplementary Figure 1)
255 indicated the model was a good fit.

256 **Discussion**

257 This paper is the first study of a random sample of English sheep flocks since 2004
258 (Kaler and Green, 2008b); we provide new evidence that the period prevalence of
259 lameness in sheep in England has fallen from 2004 to 2013 from a global mean of
260 10.6% to 4.9% and a geometric flock mean of 5.4% (sheep) to 3.5% (ewes) and 2.6%
261 (lambs). The 2013 figures were for ewes only whereas the 2004 figures were asked
262 for 'sheep' and the period lameness for lambs was less than that for ewes, so it is
263 possible that the prevalence of lameness has fallen more than to 3.5% for all sheep.
264 In addition, the distribution of lesions causing lameness has changed and CODD is
265 now contributing significantly to the prevalence of lameness.

266 This is the first observational study to provide evidence that routine foot trimming is
267 associated with a higher prevalence of lameness when feet are trimmed and bleed
268 and that prompt treatment of the first lame sheep in a group is associated with a
269 lower prevalence of lameness, that quarantine for > 3 weeks, vaccination against
270 footrot and selection of replacement stock from never-lame ewes have small but

271 significant effects on reducing the period prevalence of lameness. Changes in
272 management have also occurred with farmers adopting new recommendations when
273 one compares farmers' responses to the two questionnaires. These new findings,
274 together with other significant risk factors, are discussed below.

275 Previous studies have reported an association between routine foot trimming and
276 higher flock prevalence of lameness (Kaler and Green, 2009; Wassink, *et al.*, 2003);
277 this is the first study to report that this association is due to the rate of sheep whose
278 feet bleed when routinely trimmed. There was a biological gradient (dose effect)
279 adding to the weight of evidence for a causal relationship (Bradford Hill, 1965).
280 Once the rate of bleeding was accounted for, routine trimming alone was not
281 significantly associated with the prevalence of lameness. We conclude that it is
282 damage to living tissue in the foot that causes lameness (either directly or through
283 increased susceptibility to pathogens) rather than trimming itself. Routine foot
284 trimming was not significantly associated with prevalence of lameness once adjusted
285 for the percentage of feet bleeding (Table 3) and this indicates that there is no benefit
286 to lameness prevalence from routine foot trimming. In the current study 57% of
287 farmers were practising routine foot trimming, this is a substantial reduction from the
288 2004 estimate of 76% of farmers (Kaler and Green, 2009); farmers are changing their
289 habits and this might be in part because of technology transfer. Reduction in foot
290 trimming practices might also explain some of the reduction in the geometric mean
291 prevalence of lameness from 2004 (Kaler and Green, 2008a; Kaler and Green, 2009)
292 because if feet are not trimmed there is no risk of them being over trimmed and
293 bleeding. Given that it takes one working week for a farmer to trim 500 ewes
294 (Wassink, *et al.*, 2005), this practice uses a considerable amount of time. The results

295 from the current study therefore add weight to the proposal that routine foot
296 trimming should not be practised.

297 This is also the first study to capture information on time to treatment and number of
298 lame sheep to initiate treatment in a random sample of farmers and in a model with
299 all managements recorded; indications that these factors are important in
300 management of lameness were first reported by Kaler and Green (2008b) in a study
301 of farmer recognition of lameness in sheep. Previous papers have reported the impact
302 of treating sheep lame at locomotion score ≥ 2 (Kaler, *et al.*, 2011; Wassink, *et al.*,
303 2010) and Kaler *et al.*, (2009) and Angell *et al.*, (2015) reported that a locomotion
304 score of ≥ 2 is a highly reliable score to detect lame sheep but that score 1 has less
305 reliability. In the current study, the locomotion score (Kaler *et al.*, 2009) at which
306 farmers recognised lameness was highly correlated with the score at which they
307 caught sheep for treatment; and farmers who waited until sheep were locomotion
308 score ≥ 2 had a higher prevalence of lame sheep than those treating sheep at score ≥ 1 .
309 This suggests that farmers are able to recognise this low score consistently, possibly
310 because they become sensitised to identifying lame sheep. If farmers are now
311 reporting lameness from sheep with locomotion score 1, it is therefore possible that
312 the prevalence of lameness has fallen more than indicated by the results when
313 previously farmers routinely reported sheep with locomotion score > 1 as lame (King
314 and Green, 2011).

315 Waiting until more than five sheep were lame before treating individual lame sheep
316 was associated with significantly higher prevalence of lameness (Table 3). Cure rates
317 without treatment are low (Wassink, *et al.*, 2010), and so delaying treatment until
318 more sheep are lame for longer maintains the prevalence of lameness. Treating the
319 first lame sheep in a group promptly will also reduce the incidence of new cases of

320 lameness caused by infectious diseases. For footrot, the bacterial load of
321 *Dichelobacter nodosus* on the feet of sheep with signs of ID is high (Witcomb, *et al.*,
322 2014), indicating that these sheep are infectious and contribute to the spread footrot.
323 Delay in time to treatment might also occur when farmers found it difficult to catch
324 lame sheep; these flocks had a higher prevalence of lameness. The results from the
325 current study reinforce the efficacy of prompt individual treatment, both to cure
326 individual sheep (Kaler, *et al.*, 2010) and to reduce the spread of disease through the
327 flock (Wassink, *et al.*, 2010).

328 Recent evidence indicates that rapid cure from footrot (both ID and SFR) occurs
329 when sheep are treated with parenteral and topical antibiotics and that therapeutic
330 foot trimming reduces the rate of recovery (Kaler, *et al.*, 2010; Kaler, *et al.*, 2012;
331 Wassink, *et al.*, 2010). The proportion of farmers who treated all cases of footrot
332 with parenteral and topical antibiotics increased from 10% (where farmers stated
333 they treated 100% sheep) in 2004 (Kaler and Green, 2009) to 24% (where farmers
334 stated they ‘always’ treated such sheep) in 2013, the proportion who trimmed the feet
335 of all lame sheep fell from 69% to 44%. Because SFR and ID accounted for 90%
336 lameness in 2004, these changes in management have also probably contributed to
337 the decrease in the absolute prevalence of lameness between observed in 2013 and
338 the relative proportion attributable to footrot and ID. However, as in Kaler and Green
339 (2009), individual treatments with antibiotic injections and topical spray or
340 therapeutic foot trimming were not significantly associated with the prevalence of
341 lameness in the multivariable model in the current study (Table 3). This could be
342 because there is still an insufficient proportion of farmers always using the
343 recommended treatments (Supplementary tables) or because not all lameness (the
344 outcome in our model) is caused by ID and SFR. It is also likely that the time to

345 treatment overrides the treatment given; for example, a farmer that always using
346 antibiotic treatment but treats sheep less than once a week would still have a high
347 prevalence of lameness in their flock because of the generation time of footrot. There
348 was no correlation between time to treatment and the type of treatment used but, as
349 discussed above, rapid time to treatment was associated with a low prevalence of
350 lameness.

351 The efficacy of Footvax (MSD Animal Health) has been reported in several clinical
352 trials (Glenn, *et al.*, 1985; Hindmarsh, *et al.*, 1989; Lewis, *et al.*, 1989; Morck, *et al.*,
353 1994; MSDAnimalHealth, 2014). In all these trials the initial prevalence of lameness
354 was high (10 - 50%), with vaccination with Footvax reported to reduce the
355 prevalence of footrot by 60-90% (Glenn, *et al.*, 1985; Hindmarsh, *et al.*, 1989;
356 Lewis, *et al.*, 1989). This is the first observational study to demonstrate a reduced
357 risk of lameness in flocks that vaccinated ewes with Footvax; previous studies, where
358 few farmers were vaccinating all ewes at least once a year, have not reported a
359 significant association (Kaler and Green, 2009; Wassink, *et al.*, 2003). In the current
360 study approximately 10% farmers were vaccinating ewes at least once per year and
361 the results indicate that vaccination contributed a small, but significant, reduction in
362 the prevalence of lameness of approximately 20%. These results are consistent with
363 what is known about the vaccine, that it has low efficacy and can contribute to
364 reducing the prevalence of footrot when used with other management practices. In
365 addition to reducing susceptibility through vaccination there was a small but
366 significant effect from farmers selecting offspring from never-lame ewes for
367 replacement breeding stock. The heritability of footrot resistance is estimated at
368 about 10% (Bishop, *et al.*, 2010). It is therefore interesting to report that this is
369 detectable through an observational study.

370 As in previous studies, footbathing to prevent ID was associated with a lower risk of
371 lameness (RR 0.87) whilst footbathing to treat SFR was associated with an increased
372 risk (RR 1.12) (Table 3) (Kaler and Green, 2009; Wassink, *et al.*, 2003; 2004) and is
373 quite logical because footbaths contain disinfectants (e.g. formalin, zinc sulphate)
374 that can disinfect the surface of the foot but cannot penetrate to treat infection deep in
375 the foot and so only superficial infection is likely to respond to footbathing. In the
376 current study, footbathing was linked to behaviours that were associated with higher
377 prevalence of lameness (delaying treatment of lame sheep for more than three days
378 or until more than five sheep in a group were lame, an increased proportion of sheep
379 bleeding during routine foot trims and delaying culling until sheep had been lame
380 more than twice or were persistently lame, Supplementary Tables 3 and 4). These
381 results suggest that footbathing may not truly increase the risk of lameness but
382 because it is correlated with a sufficient number of factors that do increase the risk of
383 lameness; footbathing identifies of a group of flocks managed in this way.
384 Alternatively, the risk of lameness may be increased by close gathering sheep; if
385 some sheep in the group are lame, bringing these sheep into close proximity to other
386 sheep of recently used facilities contaminated by sheep with footrot (Whittington,
387 1995) may facilitate transmission of *D. nodosus*. Whatever the situation, footbathing
388 groups of sheep is still practised by 60% of farmers, using a variety of products, but
389 there is little evidence of its usefulness except to treat or prevent ID.

390 Culling sheep lame twice or more is strongly recommended in the UK without an
391 evidence base other than case studies, although not many farmers are practising this
392 recommendation (Table 3). In the current study, although culling sheep that had
393 been lame more than once was significant at the univariable level (Supplementary
394 Table 1) and in the multivariable sub-model (Supplementary Table 2), it was not

395 significant in the final model. This may be because farmers are still inconsistent in
396 this practice or because farmers who treated individual lame sheep promptly were
397 less likely to cull previously lame sheep. Prompt treatment results in high cure rates,
398 lower reoccurrence, better foot conformation and low flock prevalence of lameness
399 (Kaler, *et al.*, 2010; Wassink, *et al.*, 2010) and so it is possible that farmers who
400 treated lame sheep promptly and appropriately had no need to cull sheep. Among the
401 poor practices for culling, relying on memory to identify sheep for culling was
402 associated with not culling sheep until they had been lame more than twice or were
403 persistently lame and with causing bleeding during routine foot trims; all of these
404 managements were associated with higher prevalences of lameness.

405 Quarantine of new sheep on arrival was associated with a decreased risk of lameness
406 only if sheep were isolated for more than 3 weeks. This has been a suggested
407 management but never with an evidence base. It has been hypothesised that sheep
408 with footrot are most infectious in the early stages of disease (Witcomb, *et al.*, 2014),
409 and so isolating for more than 3 weeks means that disease can be recognised and
410 treated before new sheep are introduced into the flock. The incubation period for
411 CODD is unknown and so duration of quarantine to prevent introduction of CODD is
412 unknown. Sheep leaving the farm and later returning were associated with an
413 increased or decreased risk of lameness depending on the reason for re-introduction.
414 Increased prevalence of lameness would arise from increased exposure to pathogens,
415 exposure to new strains of pathogens, poor biosecurity or lack of treatment (shows,
416 summer grazing) and reduced prevalence might arise from a cold climate and naïve
417 pasture (e.g. winter grazing).

418 Some of the results from this paper used farmer naming of foot lesions. There has
419 been no substantial change in the percentage of farmers correctly naming SFR (85%

420 in 2004 and 81% in 2013) or ID (83% in 2004 and 89% in 2013) over the last ten
421 years. In contrast, the percentage of farmers correctly naming CODD has risen from
422 36% to 51% and SH has risen from 28% in 2004 (Kaler and Green, 2008a) to 58% in
423 2013 (Table 1). The misclassification of other lesions as SFR has decreased but
424 remains substantial (Table 1). As in Kaler et al., (2008b), in 2013 when farmers
425 named lesions incorrectly they ascribed the lesion to the correct name, it is therefore
426 not a misclassification but a misnaming. Data were managed as in 2004 to account
427 for the misnaming of lesions. Approximately 68% of foot lesions in flocks in 2013
428 were one of the two forms of footrot, ID or SFR (Table 1). Using farmer reported
429 lameness (farmers estimate the prevalence of lameness similar to a trained researcher
430 but with some underestimation once lameness reaches a prevalence of 10% (Kaler
431 and Green, 2008b; King and Green, 2011)), and the multivariable model (Table 2)
432 we conclude that the prevalence of SFR and CODD contribute most to the
433 prevalence of lameness. There is much discussion about SH in the UK and some
434 farmers consider it a major cause of lameness in their flock, however, shelly hoof did
435 not contribute significantly to the prevalence of lameness in the current study, despite
436 accounting for approximately 20% of all foot lesions.

437 This was a large study of English sheep flocks selected from the whole population of
438 flocks in England using stratified random sampling. The response rate was
439 reasonable and there is no evidence for response bias by geographical location. The
440 data were selected to omit hill and upland farms and flocks <200 ewes, however,
441 some flocks were in hill or upland areas with <200 ewes because the data for
442 selection were not entirely accurate. These flocks were included in the models and
443 flock size and lowland, hill, upland included in the model as explanatory variables.
444 The sample would not necessarily be representative of hill and upland flocks.

445

446 **Conclusions**

447 This is the first observational study to demonstrate that it is the proportion of sheep
448 feet that bleed during routine foot trimming that is associated with a higher
449 prevalence of lameness and that there is no benefit to foot health from routine foot
450 trimming when no sheep bleed compared with not routine foot trimming. It is also
451 the first to quantify the association between prompt treatment (within three days, and
452 when less than five sheep were lame, ease of catching sheep) and lower prevalence
453 of lameness, and a lower prevalence of lameness in flocks where the farmer
454 recognised and treated sheep lame at locomotion score 1 rather than >1 . It is also the
455 first to demonstrate a lower period prevalence of lameness in flocks where ewes were
456 vaccinated with Footvax compared with unvaccinated flocks and where never-lame
457 ewes were used to provide future breeding animals. Factors that continued to be
458 associated with low prevalence of lameness were inspection and isolation of
459 purchased and returning sheep and factors associated with a higher prevalence
460 included footbathing and a higher prevalence of lameness in lambs. There has been
461 an increase in the percentage of farmers who have stopped routine and therapeutic
462 foot trimming and started to use vaccination, select replacements from non-lame
463 ewes and always-use parenteral antibiotics to treat footrot (Supplementary tables).
464 This indicates that results from previous research is being adopted by sheep farmers.
465 The results from the model indicate that these changes in management might explain
466 some the reduction in geometric mean prevalence of lameness in sheep from 5.4% in
467 2004 when the last random survey of farmers was done to 2.6% - 3.5% in 2013.
468 Prompt treatment of lame sheep still remains a barrier to further reduce the
469 prevalence of lameness in sheep in England.

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593 **Table 1: The number and percentage of flocks by four foot lesions, correlations**
594 **between prevalence of lesions and farmer ability to name lesions**

	ID	Severe footrot	CODD	Shelly hoof
Number (%) of flocks	897 (90.5)	735 (81.6)	447 (48.7)	601 (67.0)
*Geometric mean prevalence of lesion (%)	4.5	3.1	2.3	2.9
*Proportional prevalence	42.9	25.1	11.7	20.3
Correlations between flock prevalence of lesions P<0.001				
ID				
Severe footrot	0.465			
CODD	0.284	0.460		
Shelly hoof	0.334	0.240	0.187	
Farmer name			Correct name	
Footrot (severe footrot)	81.2	5.7	22.2	17.5
ID	1.8	88.5	1.4	0.2
CODD	4.6	0.6	51.0	2.6
Shelly hoof	2.4	0.8	7.1	57.6
Other	0.3	0.8	0.8	1.4
No answer	9.8	5.1	17.5	20.7

595 **ID:** interdigital dermatitis, **CODD:** contagious ovine digital dermatitis

596 *Only farms where the lesion was present were included in prevalence estimates

597

598 **Table 2: Multivariable overdispersed Poisson regression model of associations between**
599 **foot lesions and the proportion of lame sheep on 1207 flocks 2012 - 2013**

Variable	Number	%	RR	95% CI	
Prevalence of ID					
Zero	72	6.0	1.00		
>0 - 2.5%	289	23.9	0.72	0.57	0.91
>2.5 - 5%	414	34.3	1.05	0.84	1.30
>5 - 10%	215	17.8	1.14	0.91	1.43
>10%	110	9.1	1.52	1.20	1.92
Prevalence of SFR					
Zero	139	11.5	1.00		
>0 - 2.5%	420	34.8	0.90	0.75	1.08
>2.5 - 5%	332	27.5	1.26	1.05	1.51
>5 - 10%	150	12.4	1.62	1.33	1.98
>10%	58	4.8	2.35	1.89	2.93
Prevalence of CODD					
Zero	421	34.9	1.00		
>0 - 2.5%	373	30.9	1.13	1.00	1.26
>2.5 - 5%	163	13.5	1.35	1.18	1.53
>5 - 10%	55	4.6	1.73	1.46	2.06
>10%	37	3.1	1.49	1.23	1.80
Prevalence of shelly hoof					
Zero	234	19.4	1.00		
>0 - 2.5%	413	34.2	0.85	0.75	0.97
>2.5 - 5%	216	17.9	1.05	0.92	1.20
>5 - 10%	104	8.6	1.03	0.88	1.21
>10%	64	5.3	0.77	0.63	0.94

600 N: number, %: percent, **RR**: risk ratio, **CI**: confidence interval, **ID**: interdigital dermatitis, **SFR**:
601 severe footrot, **CODD**: contagious ovine digital dermatitis
602 Risk Ratios that are significantly different from the baseline (according to Wald's test for
603 significance) are marked in **bold**

604

605 **Table 3: Multivariable over dispersed-Poisson regression model of factors**
606 **associated with the proportion of lame sheep on 1207 English farms, May 2012 -**
607 **April 2013**

Variable	Number	%	RR	95% CI	
Lowest locomotion score at which the farmer recognised sheep as lame					
1	620	52%	1.00		
2	417	35%	1.19	1.08	1.30
3+	155	13%	0.95	0.82	1.09
Number of sheep lame at locomotion score when farmers treated them					
1	163	14%	1.00		
2-5	608	52%	1.12	0.97	1.31
6-10	216	18%	1.28	1.08	1.52
10 +	185	16%	1.37	1.16	1.62
Did not treat individuals	8	1%	1.45	0.94	2.24
Time to treatment of lame sheep					
First day	82	7%	1.00		
Within 3 days	506	43%	1.13	0.92	1.39
Within a week	462	39%	1.36	1.10	1.66
More than a week	136	11%	1.43	1.14	1.80
Ease of catching individual lame sheep					
Easy / Very easy	250	21%	1.00		
Neither easy nor difficult	539	46%	1.02	0.91	1.15
Difficult / Very difficult	393	33%	1.13	1.00	1.28
Method of catching individual sheep					
Corner of field	No	848	70%	1.00	
	Yes	360	30%	0.88	0.80 0.97
Dog that can catch individuals	No	848	70%	1.00	
	Yes	360	30%	1.20	1.07 1.34
Percentage of sheep that bled during a routine foot trim, per year					
Did not trim	499	44%	1.00		
Zero	64	6%	1.10	0.86	1.39
< 1%	179	16%	0.99	0.86	1.13
1 - <5%	257	23%	1.33	1.19	1.49
5 - <10%	71	6%	1.39	1.18	1.63
10% +	61	5%	1.69	1.43	1.99
Footbath all ewes ever 2012 - 2013					
	No	485	40%	1.00	

	Yes	723	60%	1.11	0.97	1.26
Footbath to treat footrot	No	769	64%	1.00		
	Yes	439	36%	1.12	1.01	1.24
Footbath to prevent ID	No	779	64%	1.00		
	Yes	429	36%	0.87	0.79	0.96
Occasion footbathed						
At turnout	No	1,156	96%	1.00		
	Yes	52	4%	1.31	1.07	1.59
New sheep on arrival	No	767	63%	1.00		
	Yes	202	17%	1.18	1.05	1.33
No new sheep		238	20%	1.12	0.75	1.67
Culled sheep previously lame	No	646	56%	1.00		
	Yes	498	44%	1.03	0.94	1.13
Relied on memory to identify culls	No	1,046	87%	1.00		
	Yes	162	13%	1.22	1.08	1.38
Avoided selecting breeding ewes to sell from mothers that were repeatedly lame	No	1,170	97%	1.00		
	Yes	38	3%	0.77	0.60	0.99
Vaccinated ewes with Footvax	No	1010	84%	1.00		
	Yes	198	16%	0.80	0.71	0.90
Checked feet of new sheep on arrival						
Never		147	13%	1.00		
Sometimes		151	13%	0.81	0.69	0.95
Usually		242	21%	0.94	0.81	1.09
Always		387	33%	0.89	0.78	1.03
No new arrivals		239	20%	0.87	0.48	1.57
Isolated new sheep on arrival						
Did not isolate new sheep		152	13%	1.00		
Isolated for < 3 weeks		465	40%	0.93	0.80	1.08
Isolated for > 3 weeks		316	27%	0.82	0.70	0.95
No new arrivals		228	20%	0.87	0.52	1.46
Sheep left farm then returned						
For shows	No	1,157	96%	1.00		
	Yes	51	4%	1.30	1.08	1.56
For summer grazing	No	1,031	85%	1.00		
	Yes	177	15%	1.19	1.07	1.33
For market	No	1,177	97%	1.00		

	Yes	31	3%	0.72	0.53	0.96
Farm location						
Upland		120	10%	1.00		
Hill		31	3%	0.70	0.52	0.92
Lowland		1032	87%	0.82	0.73	0.93
Organic status						
Not organic		1124	95%	1.00		
Organic		63	5%	0.69	0.54	0.88
Production of breeding stock						
	No	880	73%	1.00		
	Yes	328	27%	0.87	0.79	0.97
Flock size (log 10)						
Each 10-fold increase in flock size		1208	100%	0.74	0.63	0.86
Lamb lameness prevalence						
1% increase in prevalence		1178	98%	1.03	1.03	1.04

608 N: number, %: percent, **RR**: risk ratio, **CI**: confidence interval
609 Risk Ratios that are significantly different from the baseline (according to Wald's test for
610 significance) are marked in **bold**.


611 **Model coefficient:** 0.427, **Standard Error:** 0.247

612

613

614

615 **Figure 1: An example question investigating farmer ability to name common foot**
 616 **lesions**

What you might notice when you look at the foot	Example picture of the lesion	7. What did you call this lesion? <i>Circle only one answer in each box below</i>	8. Did you see this lesion in your flock between May 2012 and April 2013? <i>Circle one answer and fill in % for each box below</i>
<ul style="list-style-type: none"> • Red, wet interdigital space • Foul smell • May be grey pasty scum • Loss of hair in interdigital space 		Footrot Scald CODD Shelly hoof Other (please state)	Yes <i>If yes, what percentage of ewes had this lesion? _____ %</i> No Do not know

617

618

619 **Supplementary material**

620 **Supplementary Table 1. The number and percentage of farmers using different**
621 **management strategies relating to lameness, and the geometric mean prevalence**
622 **of lameness for each group of farmers**

Variable	All responses		Prevalence of lameness		
	N	%	Geometric Mean	95% CI	
Lowest locomotion score at which farmer recognised sheep lame					
1	622	52.0	3.1	2.9	3.4
2	419	35.0	4.1	3.7	4.4
3	136	11.4	4.1	3.6	4.8
4+	19	1.6	4.8	3.1	7.4
Lowest locomotion score at which farmer caught lame sheep for treatment					
1	313	26.3	3.1	2.8	3.5
2	488	41.0	3.8	3.5	4.1
3	303	25.5	3.8	3.4	4.1
4	62	5.2	4.1	3.4	5.0
5	8	0.7	4.0	2.2	7.6
6	1	0.1	5.0	-	-
Did not treat individuals	14	1.2	1.3	0.3	5.6
Number lame at above score when farmers caught lame sheep for treatment					
1	163	13.8	2.5	2.1	2.9
2-5	608	51.4	3.3	3.1	3.6
6-10	216	18.2	4.6	4.1	5.2
> 10	185	15.6	5.0	4.4	5.6
Did not treat individuals	12	1.0	0.8	0.2	3.9
Time to treatment for lame sheep					
First day	82	6.9	2.4	1.9	3.0
Within 3 days	506	42.5	3.2	2.9	3.5
Within 1 week	462	38.8	4.2	3.9	4.5
Within 2 weeks	115	9.7	4.6	3.9	5.4
Longer than 2 weeks	21	1.8	5.1	3.3	7.9
Did not treat any lame sheep	4	0.3	0.0	0.0	0.3
Ease of catching individual lame sheep					
Very difficult	49	4.1	4.4	3.5	5.5
Difficult	344	29.0	3.9	3.6	4.3
Neither easy nor difficult	541	45.7	3.5	3.3	3.8

Variable	All responses		Prevalence of lameness		
	N	%	Geometric Mean	95% CI	
Easy	202	17.0	3.4	3.0	4.0
Very easy	49	4.1	2.6	1.9	3.7
Methods of catching individual lame sheep					
Central handling facility	No	511	42.3	3.2	2.9 3.5
	Yes	696	57.7	3.9	3.6 4.1
Mobile handling facility	No	947	78.5	3.6	3.4 3.9
	Yes	260	21.5	3.3	3.0 3.7
Corner of field	No	847	70.2	3.6	3.3 3.8
	Yes	360	29.8	3.5	3.2 3.9
Dog to gather flock	No	836	69.3	3.6	3.3 3.8
	Yes	371	30.7	3.6	3.2 3.9
Dog to catch individuals	No	1031	85.4	3.6	3.4 3.8
	Yes	176	14.6	3.3	2.8 3.8
Food	No	822	68.1	3.6	3.3 3.8
	Yes	385	31.9	3.6	3.2 3.9
From vehicle	No	1050	87.0	3.6	3.4 3.8
	Yes	157	13.0	3.3	2.9 3.7
Frequency of trimming the feet of ewes lame with footrot					
Never	33	2.9	1.8	1.2	2.7
Sometimes	222	19.7	3.5	3.1	3.9
Usually	382	33.9	3.9	3.6	4.2
Always	490	43.5	3.8	3.5	4.1
Frequency of treating ewes lame with footrot with antibiotic injection					
Never	82	7.3	2.8	2.2	3.6
Sometimes	475	42.2	3.9	3.7	4.3
Usually	295	26.2	4.0	3.7	4.4
Always	273	24.3	3.2	2.9	3.6
Frequency of treating ewes lame with footrot with antibiotic spray					
Never	25	2.2	2.0	1.0	3.8
Sometimes	108	9.5	3.5	2.9	4.2
Usually	258	22.6	3.8	3.4	4.2
Always	751	65.8	3.8	3.6	4.0
Frequency of separating ewes lame with footrot from the flock					
Never	508	47.6	3.6	3.3	3.9
Sometimes	472	44.2	3.9	3.7	4.2
Usually	61	5.7	2.9	2.1	4.0

Variable	All responses		Prevalence of lameness		
	N	%	Geometric Mean	95% CI	
Always	26	2.4	3.0	1.9	4.9
Type of foot spray used to treat sheep with footrot or ID					
Lincospectin solution	No	1084	89.8	3.5	3.3 3.7
	Yes	123	10.2	3.9	3.4 4.5
Antibiotic aerosol	No	165	13.7	2.7	2.2 3.3
	Yes	1042	86.3	3.7	3.5 3.9
Disinfectant aerosol	No	1054	87.3	3.6	3.4 3.8
	Yes	153	12.7	3.4	2.9 4.0
Did not use	No	1192	98.8	3.6	3.4 3.8
	Yes	15	1.2	1.2	0.4 3.0
Injectable antibiotic used to treat sheep with footrot or ID					
Oxytetracycline LA	No	458	37.9	3.2	2.9 3.5
	Yes	749	62.1	3.8	3.6 4.0
Draxxin	No	1189	98.5	3.6	3.4 3.8
	Yes	18	1.5	2.4	1.6 3.4
PenStrep	No	788	65.3	3.5	3.3 3.8
	Yes	419	34.7	3.6	3.3 3.9
Did not use	No	1137	94.2	3.6	3.4 3.8
	Yes	70	5.8	2.6	2.0 3.4
Frequency of routine foot trimming					
Never	501	42.7	3.0	2.8	3.3
Once	408	34.8	3.6	3.2	4.0
Twice	186	15.8	4.4	3.9	5.0
More than twice	79	6.7	5.3	4.3	6.6
Approximate number of sheep trimmed during a routine trim					
<25%	221	30.5	3.5	3.1	3.9
25%	122	16.9	4.7	4.0	5.6
50%	70	9.7	5.1	4.1	6.2
75%	78	10.8	4.3	3.6	5.1
100%	233	32.2	3.6	3.2	4.1
Approximate percentage of sheep that bled during a routine foot trim					
Did not trim	501	43.3	3.0	2.8	3.3
0	70	6.0	2.3	1.6	3.2
0< - 1	187	16.1	3.4	3.0	3.9
1< - 2	130	11.2	3.8	3.2	4.4
2< - 3	50	4.3	4.3	3.5	5.2

Variable	All responses		Prevalence of lameness		
	N	%	Geometric Mean	95% CI	
3<	220	19.0	5.6	5.1	6.3
Flock footbathing ewes					
	No	484	40.1	2.9	2.7 3.2
	Yes	723	59.9	4.1	3.8 4.3
Flock footbathing lambs					
	No	521	43.2	3.1	2.8 3.4
	Yes	686	56.8	4.0	3.7 4.3
Reason for footbathing					
Treating ID	No	613	50.8	3.2	2.9 3.4
	Yes	594	49.2	4.0	3.8 4.3
Treating footrot	No	768	63.6	3.1	2.9 3.3
	Yes	439	36.4	4.5	4.2 4.9
Preventing ID	No	778	64.5	3.5	3.2 3.7
	Yes	429	35.5	3.7	3.4 4.1
Preventing footrot	No	780	64.6	3.4	3.2 3.6
	Yes	427	35.4	3.9	3.6 4.3
Substance used for footbathing					
Zinc sulphate	No	956	79.2	3.5	3.3 3.7
	Yes	251	20.8	3.9	3.4 4.3
Copper sulphate	No	1136	94.1	3.5	3.3 3.7
	Yes	71	5.9	4.6	3.9 5.4
Formalin	No	643	53.3	3.2	2.9 3.5
	Yes	564	46.7	4.0	3.7 4.3
Lincospectin	No	1088	90.1	3.5	3.3 3.7
	Yes	119	9.9	4.2	3.6 4.9
Occasion when sheep were footbathed					
Before Housing	No	951	78.8	3.4	3.2 3.6
	Yes	256	21.2	4.3	3.9 4.7
At turnout	No	1155	95.7	3.5	3.3 3.7
	Yes	52	4.3	4.2	3.3 5.3
Moving between fields	No	966	80.0	3.3	3.1 3.6
	Yes	241	20.0	4.6	4.1 5.0
After gathering	No	852	70.6	3.3	3.1 3.5
	Yes	355	29.4	4.3	3.9 4.7
New sheep on arrival	No	775	64.2	3.5	3.3 3.8
	Yes	202	16.7	4.1	3.6 4.6

Variable	All responses		Prevalence of lameness		
	N	%	Geometric Mean	95% CI	
No new sheep	230	19.1	3.2	2.8	3.6
Sheep returning to farm	No	1103	91.4	3.5	3.3 3.7
	Yes	104	8.6	4.7	4.1 5.4
Frequency of routine footbathing of ewes at pasture					
Once a week	8	1.3	4.6	2.6	8.0
Once a fortnight	78	12.9	4.4	3.8	5.2
Once a month	216	35.6	4.6	4.2	5.2
Other	20	3.3	3.5	2.5	4.9
Did not routinely footbath ewes at pasture	284	46.9	3.3	2.9	3.7
Frequency of routine footbathing lambs at pasture					
Once a week	16	2.6	5.9	4.2	8.4
Once a fortnight	93	14.8	4.3	3.6	5.0
Once a month	199	31.7	4.3	3.9	4.8
Other	14	2.2	2.7	2.0	3.7
Did not routinely footbath lambs at pasture	305	48.6	3.3	2.9	3.8
Frequency of routine footbathing ewes when housed					
Once a week	34	4.6	4.1	3.2	5.4
Once a fortnight	53	7.1	4.8	3.9	5.9
Once a month	85	11.4	4.5	3.9	5.2
Other	4	0.5	3.8	2.5	5.8
Did not routinely footbath ewes when housed	368	49.5	3.8	3.5	4.2
Did not house ewes	199	26.8	3.3	2.9	3.8
Frequency of routine footbathing lambs when housed					
Once a week	28	3.8	3.9	3.1	5.0
Once a fortnight	43	5.9	5.5	4.3	7.1
Once a month	28	3.8	4.0	3.1	5.1
Other	4	0.5	3.8	2.5	5.8
Did not routinely footbath lambs housed	180	24.6	3.9	3.3	4.5
Did not house lambs	448	61.3	3.7	3.4	4.1
Cull sheep when they are lame					
No	783	66.9	3.4	3.1	3.6
Yes	387	33.1	4.0	3.6	4.3
Cull sheep that had been lame previously					
No	648	56.5	3.4	3.2	3.7
Yes	499	43.5	3.7	3.4	4.0

Variable	All responses		Prevalence of lameness		
		N	%	Geometric Mean	95% CI
Number of lameness episodes prior to culling					
Did not cull		626	54.7	3.4	3.1 3.7
1		38	3.3	1.7	1.1 2.7
1< - 2		142	12.4	3.3	2.9 3.8
2<		299	26.1	4.2	3.9 4.6
Persistently lame		40	3.5	4.3	3.4 5.4
Method for identifying sheep for culling					
Memory	No	1045	86.6	3.4	3.2 3.6
	Yes	162	13.4	4.5	3.9 5.0
EID ear tag	No	1148	95.1	3.6	3.4 3.8
	Yes	59	4.9	3.2	2.5 4.3
non-EID tag	No	1074	89.0	3.5	3.3 3.8
	Yes	133	11.0	3.7	3.2 4.2
Coloured spray	No	764	63.3	3.4	3.2 3.7
	Yes	453	37.5	3.8	3.5 4.1
Avoid selection of replacement ewes from mothers that were repeatedly lame					
Not at all	No	672	55.7	3.4	3.2 3.7
	Yes	535	44.3	3.7	3.4 4.0
Yes, for my flock	No	877	72.7	3.6	3.4 3.8
	Yes	330	27.3	3.5	3.1 3.8
Yes, for other peoples flocks	No	1169	96.9	3.6	3.4 3.8
	Yes	38	3.1	2.5	1.8 3.5
Did not breed replacement ewes	No	901	74.6	3.5	3.3 3.7
	Yes	306	25.4	3.8	3.4 4.3
Vaccination with Footvax					
Ewes	No	1009	83.6	3.7	3.5 3.9
	Yes	198	16.4	2.9	2.4 3.4
Rams	No	987	81.8	3.7	3.5 3.9
	Yes	220	18.2	2.9	2.5 3.4
Sheep with footrot	No	1172	97.1	3.5	3.4 3.8
	Yes	35	2.9	3.9	2.6 5.9
Bought-in sheep	No	1122	93.0	3.7	3.5 3.9
	Yes	85	7.0	2.4	1.8 3.2
Frequency of vaccination with Footvax					
Once a year	No	16	7.3	3.6	3.4 3.8
	Yes	204	92.7	3.4	2.3 5.0

Variable		All responses		Prevalence of lameness		
		N	%	Geometric Mean	95% CI	
Twice a year	No	172	78.2	3.6	3.4	3.8
	Yes	48	21.8	3.4	2.6	4.5
Before an expected peak	No	198	90.0	3.6	3.4	3.8
	Yes	22	10.0	2.8	1.4	5.6
Once in sheep's lifetime	No	201	91.4	3.6	3.4	3.8
	Yes	19	8.6	4.4	3.5	5.6
Whole flock antibiotic injection						
	Yes	82	6.8	4.2	3.6	5.1
	No	1109	91.9	3.5	3.3	3.7
Reason for injection						
Footrot	No	31	37.8	3.5	3.3	3.7
	Yes	51	62.2	4.5	3.7	5.4
Toxoplasma abortion	No	46	56.1	3.5	3.4	3.8
	Yes	36	43.9	3.9	3.0	5.1
Enzootic abortion	No	25	30.5	3.5	3.3	3.7
	Yes	57	69.5	4.2	3.4	5.1
Antibiotic used						
Oxytetracycline LA	No	20	24.4	3.5	3.3	3.7
	Yes	62	75.6	4.3	3.7	5.1
PenStrep	No	75	91.5	3.5	3.4	3.7
	Yes	7	8.5	4.3	3.2	5.7
Micotil	No	78	95.1	3.6	3.4	3.8
	Yes	4	4.9	4.6	3.2	6.5
Draxxin	No	79	96.3	3.6	3.4	3.8
	Yes	3	3.7	5.2	2.6	10.4
Check the feet of sheep before purchase						
	Never	189	15.9	3.9	3.5	4.4
	Sometimes	173	14.5	4.0	3.4	4.6
	Usually	249	20.9	4.1	3.7	4.6
	Always	324	27.2	3.1	2.8	3.4
	Did not purchase	255	21.4	3.3	2.9	3.7
Check the feet of new sheep on arrival						
	Never	147	12.6	3.7	3.1	4.5
	Sometimes	151	12.9	4.0	3.5	4.5
	Usually	243	20.8	4.3	3.8	4.7
	Always	388	33.2	3.2	2.9	3.5

Variable	All responses		Prevalence of lameness		
	N	%	Geometric Mean	95% CI	
No new arrivals	241	20.6	3.2	2.9	3.6
Treat new sheep with footrot or ID on arrival					
Never	312	27.6	3.5	3.1	3.9
Sometimes	194	17.2	4.0	3.5	4.5
Usually	121	10.7	4.7	4.2	5.3
Always	265	23.5	3.4	3.0	3.8
No new arrivals	238	21.1	3.2	2.8	3.6
Isolation of new sheep on arrival					
Never	153	13.1	4.0	3.3	4.7
Sometimes	99	8.4	3.7	3.1	4.5
Usually	169	14.4	4.2	3.7	4.7
Always	521	44.5	3.3	3.1	3.7
No new arrivals	230	19.6	3.2	2.8	3.6
Duration of isolation of new sheep on arrival					
Isolated for < 1 week	74	9.3	3.9	3.3	4.6
Isolated for 1-3 weeks	402	50.3	3.9	3.6	4.2
Isolated for > 3 weeks	323	40.4	3.2	2.8	3.6
Sheep leaving the farm and later returning					
Yes, for shows	No	1156	95.8	3.5	3.3 3.7
	Yes	51	4.2	4.0	3.1 5.1
Yes, when sharing rams	No	1182	97.9	3.6	3.4 3.8
	Yes	25	2.1	2.9	2.2 4.0
Yes, for summer grazing	No	1030	85.3	3.5	3.3 3.7
	Yes	177	14.7	4.1	3.6 4.7
Yes, for winter grazing	No	890	73.7	3.5	3.3 3.7
	Yes	317	26.3	3.7	3.4 4.1
Yes, back from market	No	1176	97.4	3.6	3.4 3.8
	Yes	31	2.6	2.7	2.1 3.6
Isolation of sheep returning to the farm					
Never	287	54.7	3.9	3.5	4.3
Sometimes	89	17.0	3.7	3.0	4.6
Usually	93	17.7	3.9	3.3	4.5
Always	56	10.7	3.8	3.0	4.7
Duration of isolation of sheep returning to the farm					
< 1 week	50	19.7	3.9	3.2	4.7
1 - 3 weeks	144	56.7	4.3	3.7	4.9

Variable	All responses		Prevalence of lameness		
	N	%	Geometric Mean	95% CI	
> 3 weeks	60	23.6	3.2	2.7	3.9
Mixing of sheep with neighbouring flocks					
Yes	53	4.5	4.3	3.6	5.1
No	1116	94.9	3.6	3.4	3.8
Don't know	7	0.6	1.5	0.4	6.5
Farmer sex					
Male	1040	87.1	3.5	3.3	3.8
Female	154	12.9	3.6	3.1	4.2
Farmer age					
< 25	21	1.8	4.6	3.2	6.7
26-35	73	6.1	3.6	3.0	4.3
36-45	178	14.8	3.4	3.0	3.9
46-55	399	33.3	3.6	3.3	4.0
56-65	313	26.1	3.7	3.3	4.0
> 65	211	17.6	3.3	2.8	3.8
Do not wish to say	4	0.3	4.1	1.6	10.2
Land type					
Hill	32	2.7	2.6	1.7	4.1
Upland	120	10.1	3.8	3.2	4.6
Lowland	1035	87.2	3.6	3.4	3.8
Organic status					
Not organic	1128	94.7	3.7	3.5	3.9
Organic	63	5.3	2.3	1.8	3.0
Approximate stocking rate of ewes					
< 4 ewes / acre	521	44.7	3.2	3.0	3.5
4 - 8 ewes/acre	593	50.9	3.9	3.6	4.2
> 8 ewes/acre	51	4.4	3.8	2.7	5.4
Source of replacement ewes					
Bought-in	No	705	58.4	3.2	2.9 3.5
	Yes	502	41.6	3.9	3.6 4.1
Homebred	No	790	65.5	4.0	3.6 4.3
	Yes	417	34.5	3.4	3.1 3.6
Production on farm					
Finished lambs	No	99	8.2	3.6	3.1 4.2
	Yes	1108	91.8	3.6	3.4 3.8
Store lambs	No	875	72.5	3.6	3.4 3.9

Variable	All responses		Prevalence of lameness			
		N	%	Geometric Mean	95% CI	
Breeding stock	Yes	332	27.5	3.4	3.1	3.7
	No	879	72.8	3.8	3.5	4.0
	Yes	328	27.2	3.0	2.7	3.3
Housing of sheep						
Ewes	No	341	28.3	3.1	2.8	3.5
	Yes	866	71.7	3.7	3.5	4.0
Lambs	No	968	80.2	3.6	3.4	3.8
	Yes	239	19.8	3.5	3.1	3.9
Frequency fresh bedding added to pens for ewes						
Daily		374	47.1	3.6	3.3	4.0
Every two days		328	41.3	4.2	3.8	4.5
Weekly		92	11.6	3.6	3.0	4.5
Condition of bedding in pen when fresh bedding added						
Dry	No	718	59.5	3.6	3.3	3.8
	Yes	488	40.4	3.5	3.2	3.8
Damp	No	856	70.9	3.4	3.1	3.6
	Yes	351	29.1	4.1	3.7	4.4
Wet	No	1188	98.4	3.6	3.4	3.8
	Yes	19	1.6	3.3	2.3	4.6
Soiled	No	1013	83.9	3.5	3.3	3.8
	Yes	194	16.1	3.7	3.2	4.2

623 N: number, %: percent, CI: confidence interval

624

625 **Supplementary Table 2: Overdispersed Poisson regression models of nine sub-**
626 **categories from the questionnaire**

627 a) factors relating to the recognition and catching of lame sheep associated with the
628 proportion of lame sheep May 2012 - April 2013

Variable	All responses		RR	95% CI	
	N	%			
Lowest locomotion score at which the farmer recognised sheep as lame					
1	620	51.5	1.00		
2	417	34.7	1.31	1.17	1.46
3	136	11.3	1.26	1.06	1.50
4+	19	1.6	1.59	1.10	2.31
Number of sheep required to be lame at the above locomotion score for farmers to catch and treat them					
1	163	13.5	1.00		
2-5	608	50.5	1.22	1.00	1.48
6-10	216	18.0	1.64	1.33	2.02
>10	185	15.4	1.59	1.29	1.95
Did not treat individuals	8	0.7	1.10	0.63	1.93
Time to treatment for lame sheep					
First day	82	6.8	1.00		
Within 3 days	506	42.1	1.11	0.86	1.44
Within 1 week	462	38.4	1.32	1.02	1.70
Within 2 weeks	115	9.6	1.54	1.17	2.03
Longer than 2 weeks	21	1.7	1.30	0.89	1.91
Did not treat any lame sheep	Excl.	Excl.			
Method of catching individual lame sheep					
Central handling facility	No	515	42.4	1.00	
	Yes	693	57.6	1.17	1.05
Food	No	823	68.0	1.00	
	Yes	385	32.0	1.14	1.02
From vehicle	No	1,051	86.9	1.00	
	Yes	157	13.1	0.81	0.69

629 b) factors relating to the treatment of sheep with footrot associated with the proportion of
630 lame sheep in 2013

Variable		All responses		RR	95% CI	
		N	%			
Frequency of trimming feet of ewes when lame with footrot						
Never		32	2.8	0.51	0.34	0.77
Sometimes		222	19.7	0.78	0.67	0.91
Usually		382	33.9	0.91	0.80	1.04
Always		490	43.5	1.00		
Frequency of treating ewes lame with footrot with an antibiotic injection						
Never/ Sometimes/ Usually		851	70.7	1.00		

	Always	273	22.7	0.78	0.68	0.90
	Injectable antibiotic used to treat sheep with footrot or ID					
	PenStrep	No	720	65.3	1.00	
		Yes	418	34.7	0.86	0.76 0.97
631	c) factors relating to the routine foot trimming of sheep associated with the proportion of					
632	lame sheep in 2013					
	Variable	All responses		RR	95% CI	
		N	%			
	Average number of foot trims per sheep per year					
	Zero	499	41.5	1.00		
	0.125	84	7.0	1.21	0.88	1.67
	0.25 - 1.5	501	41.6	1.45	1.12	1.88
	2	67	5.6	1.65	1.18	2.31
	3+	13	1.1	2.70	1.47	4.95
	Approximate percentage of sheep that bled during a routine foot trim					
	Did not trim	499	41.5	1.00		
	0	70	5.8	0.67	0.46	0.97
	0< - 1	187	15.5	0.90	0.68	1.20
	1< - 2	129	10.7	0.98	0.73	1.32
	2< - 3	50	4.2	1.00	1.00	1.00
	3<	220	18.3	1.39	1.06	1.81
633	d) association between the percentage of sheep on a farm that bled during a routine foot trim					
634	in 2013 and the proportion of lame sheep in 2013					
	Variable	All responses		RR	95% CI	
		N	%			
	Percentage of sheep that bled during a routine foot trim, per year					
	Did not trim	499	44%	1.00		
	Zero	64	6%	1.10	0.86	1.40
	<1%	179	16%	0.99	0.86	1.13
	1 - <5%	257	23%	1.33	1.19	1.49
	5 - <10%	71	6%	1.39	1.19	1.64
	10% +	61	5%	1.69	1.43	1.99
635	e) factors relating to whole flock footbathing associated with the proportion of lame sheep in					
636	2013					
637						
	Variable	All responses		RR	95% CI	
		N	%			
	Flock footbathing					
	No	772	63.9			
	Yes	436	36.1	1.16	0.79	1.72
	Reason for footbathing					
	Treating ID	No	614	50.8	1.00	
		Yes	594	49.2	0.82	0.69 0.97
	Treating footrot	No	769	63.7	1.00	
		Yes	439	36.3	1.30	1.13 1.50

Preventing ID	No	779	64.5	1.00		
	Yes	429	35.5	0.71	0.61	0.82
Time at which sheep were footbathed						
Moving between fields	No	966	80.0	1.00		
	Yes	241	20.0	1.37	1.18	1.59
After gathering	No	852	70.6	1.00		
	Yes	355	29.4	1.18	1.02	1.35
New sheep on arrival	No	767	63.5	1.00		
	Yes	202	16.7	1.22	1.04	1.43
No new sheep		238	19.7	0.91	0.75	1.12
Frequency of routine footbathing of lambs at pasture						
Once a week		16	1.3	1.00		
Once a fortnight		93	7.7	0.74	0.52	1.06
Once a month		199	16.5	0.83	0.60	1.15
Other		14	1.2	0.45	0.23	0.89
Did not routinely footbath lambs at pasture		304	25.3	0.68	0.48	0.95
Frequency of routine footbathing of lambs when housed						
Once a week		28	2.3	1.00		
Once a fortnight		43	3.6	1.68	1.17	2.41
Once a month		28	2.3	0.96	0.62	1.49
Other		4	0.3	1.26	0.60	2.66
Did not routinely footbath lambs when housed		180	15.0	1.11	0.79	1.58
Did not house lambs		447	37.2	1.03	0.74	1.42

638

639 f) factors relating to culling and replacement ewes associated with the proportion of lame
640 sheep in 2013

Variable	All		RR	95% CI	
	responses				
	N	%			
Number of lameness episodes prior to culling					
Did not cull	589	49.0	1.00		
Once	36	3.0	0.54	0.34	0.83
Twice	142	11.8	0.77	0.60	0.99
More than twice	299	24.9	0.90	0.71	1.14
Persistently lame	40	3.3	1.29	0.92	1.79
Method of identifying sheep for culling					
Memory	No	1,046	86.5	1.00	
	Yes	162	13.5	1.27	1.05 1.55

641

642 g) factors relating to biosecurity associated with the proportion of lame sheep in 2013

Variable	All responses		RR	95% CI	
	N	%			
Checking the feet of sheep before purchase					
Never/Sometimes/Usually	610	50.7	1.00		
Always	324	26.9	0.73	0.64	0.83
Did not purchase	253	21.0	0.93	0.63	1.39
Duration of isolation of new sheep on arrival					
No new arrivals	228	19.0	0.79	0.52	1.22
Did not isolate	152	12.6	1.00		
Isolated for <1 week	68	5.7	0.85	0.64	1.14
Isolated for 1-3 weeks	397	33.0	0.98	0.81	1.18
Isolated for >3 weeks	316	26.3	0.80	0.66	0.97
Sheep leaving the farm and returning later					
Yes, for summer grazing	No	1,031	85.3	1.00	
	Yes	177	14.7	1.18	1.03 1.35

643

644 h) factors relating to characteristics of the farm and farmer associated with the proportion of
645 lame sheep in 2013

Variable	All responses		RR	95% CI	
	N	%			
Land type					
Upland	120	10.0	1.00		
Hill	31	2.6	0.78	0.59	1.04
Lowland	1,032	85.8	0.84	0.74	0.97
Organic status					
Not organic	1,124	93.4	1.00		
Organic	63	5.2	0.70	0.54	0.90
Flock size (log 10)					
For each 10-fold increase in flock size	1,208	100.0	0.76	0.66	0.87
Average prevalence of lameness in lambs					
For each percent increase in lamb lameness prevalence	1,178	97.9	1.04	1.04	1.04
Production on farm					
Breeding stock	No	880	72.7	1.00	
	Yes	328	27.3	0.83	0.75 0.93
Housing of ewes					
	No	344	28.2	1.00	
	Yes	864	71.8	1.17	1.05 1.31

646 N: number, %: percent, **RR**: risk ratio, **CI**: confidence interval647 Risk Ratios that are significantly different from the baseline (according to Wald's test for
648 significance) are marked in **bold**.

650

651 **Correlations and associations between variables in the final model and**
652 **significant variables in the sub-multivariable models**

653 *Factors associated with catching and treating lame sheep*

654 The score at which farmers recognised lameness was highly correlated with the score
655 at which they caught lame sheep for treatment ($P < 0.001$). Farmers who recognised
656 lameness at score 1 typically found it easy to catch lame sheep, and were more likely
657 to catch sheep for treatment when less than five sheep were lame in a group than
658 farmers who recognised lameness at score 2 (Table 10). These behaviours were
659 associated with smaller flock sizes.

660 Farmers who found catching individual lame sheep ‘easy’ were more likely to catch
661 sheep for treatment within three days of seeing them lame than farmers who found it
662 difficult to catch individual lame sheep. Farmers who caught lame sheep the first day
663 they saw them lame typically caught them in the corner of the field. Farmers who
664 treated individual lame sheep promptly were less likely to cull sheep that had been
665 lame whereas farmers who delayed treating individual lame sheep were more likely
666 to either cull sheep after a single lameness episode or wait until sheep were
667 persistently lame before culling (Table 11).

668 Farmers who used a central handling facility to catch individual lame sheep were
669 more likely to wait until more than ten sheep were lame before treating them, less
670 likely to treat individual lame sheep within three days and typically found it more
671 difficult to catch individual lame sheep.

672 Farmers who always treated individual lame sheep with footrot with an antibiotic
673 injection were less likely to routinely foot trim their flocks than farmers who never

674 treated lame sheep with an antibiotic injection. Farmers who always treated lame
675 sheep with an antibiotic injection were more likely to vaccinate ewes, cull sheep that
676 had been lame, isolate new sheep and check the feet of new sheep on arrival than
677 farmers who did not always inject sheep with footrot.

678 ***Factors associated with routine and therapeutic foot trimming***

679 Farmers who treated lame sheep within three days of seeing them lame were less
680 likely to routinely foot trim and cause bleeding than farmers who delayed treatment
681 by longer than three days (Table 10).

682 There was a positive association between therapeutic foot trimming and the
683 proportion of sheep bleeding during a routine foot trim. Therapeutic foot trimming
684 was negatively associated with footbathing to treat footrot and culling sheep that had
685 been lame, but was positively associated with relying on memory to identify sheep
686 for culling. There was a positive association between recognition of lameness at
687 higher lameness scores and an increased likelihood of therapeutic foot trimming.
688 Farmers who found catching individual lame sheep easy were more likely to always
689 trim the feet of lame sheep than farmers who found it difficult to catch individual
690 lame sheep (Table 11). Farmers who always trimmed the feet of individual lame
691 sheep typically had smaller flocks than farmers who never trimmed lame sheep.

692 ***Factors associated with routine and therapeutic footbathing***

693 Farmers who footbathed routinely were more likely to routinely trim feet and cause
694 bleeding than farmers who did not footbath (Table 10). They were also more likely to
695 check the feet of new sheep on arrival and isolate new sheep for more than three
696 weeks. Farmers who footbathed were likely to wait until more than 5 sheep were
697 lame before treating lame sheep. Organic farmers were more likely to routinely

698 footbath than farmers who did not farm farm organically. Routine footbathing was
699 also associated with increased flock size.

700 ***Factors associated with culling and biosecurity***

701 Farmers who vaccinated their sheep with Footvax were more likely to cull sheep that
702 had been lame than farmers who did not vaccinate their sheep (Table 10). Culling
703 sheep that had been lame was associated with delaying treating lame sheep for longer
704 than a week. Farmers who footbathed to treat footrot were likely to delay culling
705 sheep until they had been lame more than twice or were persistently lame (Table 11).
706 Farmers who selected replacement ewes from non-lame mothers were more likely to
707 cull sheep that had been lame. Farmers relying on their memory to identify sheep for
708 culling were more likely to cull persistently lame sheep or sheep that had been lame
709 more than twice.

710 Farmers who culled lame sheep after a single lameness episode were more likely to
711 "always" check the feet of new sheep on arrival. Farmers who did not cull sheep for
712 lameness were less likely to purchase new sheep. Culling lame sheep after a single
713 lameness episode was associated with isolating new sheep for more than three weeks
714 (Table 11). Farmers who did not cull until sheep were persistently lame or had been
715 lame more than twice were likely to isolate for less than three weeks. Farmers with
716 smaller flocks were less likely to cull sheep that had been lame (Table 10). Farmers
717 producing breeding stock were more likely to select replacement ewes from mothers
718 that had not been lame.

719 Farmers were more likely to 'always' check the feet of new sheep before purchase or
720 on arrival if they also recognised lameness at low locomotion scores (Table 10) and
721 treated individual lame sheep promptly (Table 11). Checking the feet of new sheep

722 before purchase or on arrival were positively associated with routine footbathing,
723 isolating new sheep and producing breeding stock.

Supplementary Table 3: Significant ($P \leq 0.05$) associations (as determined by χ^2 test or ANOVA) between variables in the full risk factor model

	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Percentage of sheep that bled during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Score at which farmer recognises lameness		+		-																				-		
Number of lame sheep in a group before treating lame sheep	+		+		-			+	+								-							-	+	+
Time to treatment		+		-			+		+		-	+			+		-								+	+
Ease of catching (Difficult to easy)	-		-			+					+			+	-								+			
Catch in corner of field		-				+								+				+						+	+	
Catch individuals with a dog				+	+		-						+					+		+		a	+	+		
Percentage of sheep that bled during a routine foot trim, per year			+			-		+	+			-	+			-	b								c	+
Routine footbath any sheep		+					+		+	+	+	+	+			+	+	+					+		+	+

	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Percentage of sheep that bled during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Footbath to treat footrot	+	+				+	+			+	+	+		+			+			+		+		+	+	
Footbath to prevent ID								+	+		+	+		+		+	+	+	+				+	+	+	
Footbath at turnout			-	+				+	+	+		+														
Footbath new sheep on arrival								+	+	+	+					+	+	+	+						+	
Cull sheep that had been lame			+		+	-	+							+	+	+	+	+						+		
Rely on memory to identify sheep for culling				+	+	+		+	+			+								+	+			+	+	
Select replacement sheep from non-lame mothers			+	-								+												+		
Vaccinate ewes						-	+	+	+		+	+										d		+		
Check feet of new sheep on arrival	-	-				b	+	+	+	+	+	+						+				e	+	+	f	
Duration of isolation of new sheep					+	+	+		+		+	+					+						+	+		
Sheep left farm for shows										+		+								+	+		+			
Sheep left farm for summer grazing					+			+						+				+			+			+	+	

	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Percentage of sheep that bled during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Sheep left for market														+					+	+			+			
Farm location						a										d									g	
Organic status				+				+	+	+							e	+								-
Produce breeding stock	-	-			+	+				+					+		+		+	+	+					
Flock size (small to large)		+	+		+	+	c	+	+	+		+	+	+		+	+	+		+		g				
Lamb lameness prevalence		+	+				+	+	+					+			f			+			-			

+ indicates a positive association, - indicates a negative association. Non-significant associations are not shown, P values for all associations are shown in Appendix 4

Non-ordinal associations:

a: Using a dog to catch individual sheep was more likely on hill or upland farms than lowland farms, **b:** “Never” checking feet on arrival was associated with not foot trimming, **c:** Not foot trimming was associated with a larger flock size, **d:** No ewes were vaccinated with Footvax on hill farms, **e:** Organic farms were more likely to have no new sheep, **f:** Having no new sheep or “always” checking feet on arrival was associated with a higher prevalence of lameness in lambs than “usually” checking feet on arrival, **g:** Lowland flocks were typically smaller than hill or upland flocks

Supplementary Table 4: Significant ($P \leq 0.05$) associations (as determined by χ^2 test or ANOVA) between variables in the full risk factor model (columns) and variables that were significant in the multivariable sub-models but not significant in the final model (rows)

	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Proportion of sheep bleeding during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Catch using a central handling facility		+	+	-		-		+		+							+ ^a	+ ^a							+	
Catch using food			-		+									+			- ^b			+					+	
Catch using a vehicle					+	+	-						+							+		-			+	
Therapeutic use of foot trimming	+			+			+		-				-	+											-	
Therapeutic use of antibiotic injection						+	-						+			+	+	+							+	
Use of PenStrep antibiotic injection				+	+		+																		+	
Footbathing to prevent footrot							+	+	+	+	+	+		+			+	+				-				
Footbathing when moving between fields							+	+	+	+	+	+					+						-		+	
Footbathing after gathering		-						+	+	+	+	+	+	+			+	-		+		-		-	+	
Number of lameness episodes before culling			+			+	-	+	+			+	+	+	+	+	+	+ ^c					+		+	+

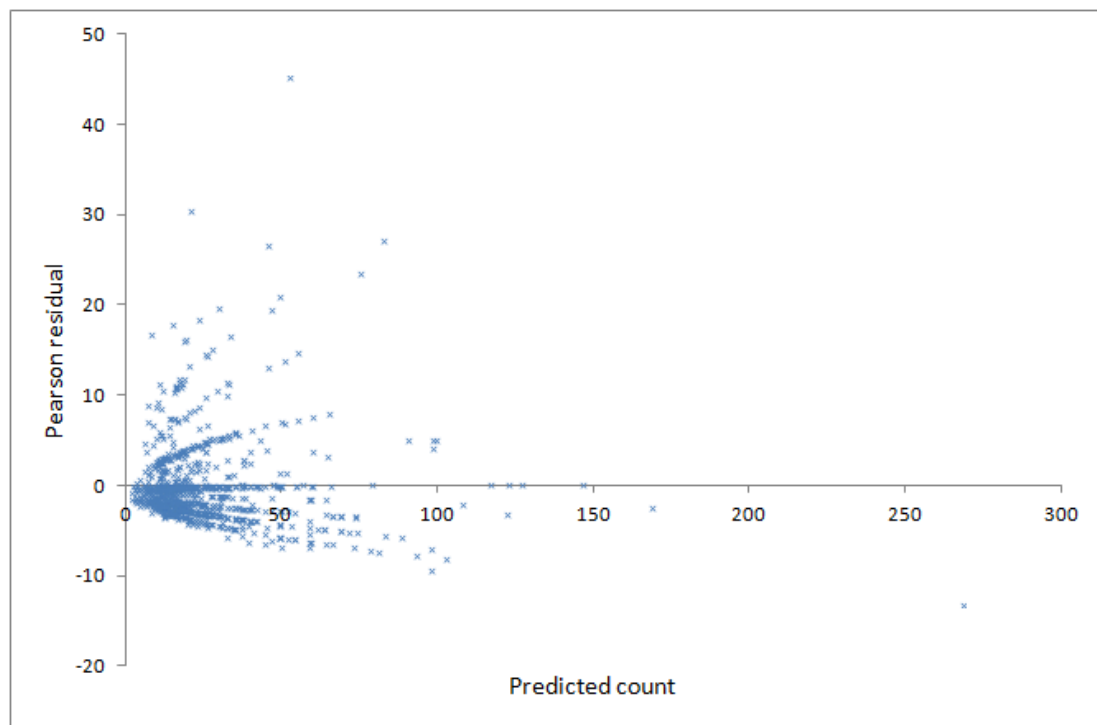
	Score at which farmer recognises lameness	Number of lame sheep in a group before treating lame sheep	Time to treatment	Ease of catching (Difficult to easy)	Catch in corner of field	Catch individuals with a dog	Proportion of sheep bleeding during a routine foot trim, per year	Routine footbath any sheep	Footbath to treat footrot	Footbath to prevent ID	Footbath at turnout	Footbath new sheep on arrival	Cull sheep that had been lame	Rely on memory to identify sheep for culling	Select replacement sheep from non-lame mothers	Vaccinate ewes	Check feet of new sheep on arrival	Duration of isolation of new sheep	Sheep left farm for shows	Sheep left farm for summer grazing	Sheep left for market	Farm location	Organic status	Produce breeding stock	Flock size (small to large)	Lamb lameness prevalence
Check feet of new sheep before purchase	-		-				+	+	+	+		+	+		+		+	+			d		e	+	+	-
Housing of ewes	-					-				-	+	+					f	f	+			g	h			

+ indicates a positive association, - indicates a negative association. Non-significant associations are not shown, P values for all associations are shown in Appendix 5

Non-ordinal associations:

a: Farmers without a central handling facility were less likely to purchase new sheep, **b:** Farmers who used food to catch sheep were less likely to purchase new sheep, **c:** Farmers who did not cull were less likely to have new sheep, **d:** Farmers whose sheep returned from market were less likely to purchase new sheep, **e:** Organic farmers were less likely to purchase new sheep, **f:** Farmers who housed sheep were less likely to have new sheep, **g:** Hill farmers were less likely to house sheep, **h:** Organic farmers were less likely to house sheep

1 **Supplementary Figure 1: Pearson residuals plotted against the model predictions**



2

3

4

5